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# Farm-Level Impacts of Banning Growth-Promoting Antibiotic Use in U.S. Pig Grower/Finisher Operations

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Antibiotics have been used by pig producers for several decades, and are now used routinely. This study documents the current productivity and economic impacts of the use of antibiotics for growth promotion (AGP) by pig grower/finishers at the farm level. We evaluate the impacts of an AGP ban, and use of AGP by all pig grower/finishers for 61–90 days (a more production-efficient level), using data from the National Animal Health Monitoring System Swine 2000 Survey. Findings indicate that pig productivity improves with AGP. Relative to current use, an AGP ban would decrease producer profits by $1,400 per 1,020-head barn, and profits would increase by $1,992 for each grower/finisher barn when AGP is fed for 61 to 90 days. There is increasing concern about the use of antibiotics in animal production, partly because of the selection for antibiotic resistance. Thus, a careful examination of the value of AGP in pork production is warranted.

***Key Words:*** antibiotics, antimicrobial resistance, growth promotion, pigs, production

Antibiotics have been used in animal production for several decades. The amount of antibiotics used in animal feeds increased in the 1950s and 60s, and had reached about 2.2 million pounds by 1963 (Cromwell, 1991). Antibiotics are recognized as an important tool for efficient animal production (Miller et al., 2003; Cromwell, 2002), and routine use has occurred since at least 1990 (Miller et al., 2003). In 2000, 88.5% of farms used antibiotics for any reason, and 63.7% reported using antibiotics for growth promotion (USDA/APHIS/VS/NAHMS, 2002).

Producers use antibiotics for multiple purposes, administering them in a variety of ways. The most common use of antibiotics in 2000 was for growth promotion. Antibiotics for growth promotion (AGP) and antibiotics for disease prevention

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(ADP) are often administered at subtherapeutic levels, i.e., at concentrations below those used to treat clinical disease.

Increasingly, expressions of concern are emerging from public health officials about the use of antibiotics in animal production, at least partially because of the antibiotic resistance issue. The use of antibiotics for any purpose can be associated with selecting organisms that have antimicrobial resistance. Some portion of any population of microbes has resistance mechanisms. Such microbes are more likely to survive and grow in animals receiving antibiotics than are microbes without resistance. Limiting AGP and ADP may decrease antimicrobial resistance. Thus, continued consideration of the value of AGP and ADP in swine production is warranted.

Despite widespread concerns about antibiotic use in food animal production, there is no hard scientific evidence to support a clear-cut relationship between AGP and adverse consequences on human health (Barber, Miller, and McNamara, 2003; Casewell et al., 2003; Phillips et al., 2004; Mathews, 2001). Use of AGP has been banned in the European Union, at least partly because of antibiotic resistance concerns. This withdrawal of AGP has been associated with deterioration of animal health and increased usage of therapeutic antibiotics in food animals (Casewell et al., 2003). While there is concern about the transfer of antibiotic resistance determinants from animals to humans (USDA/APHIS/VS/CEAH, 1999; McEwen and Fedorka-Cray, 2002), significant gaps in knowledge about microbial ecology and antibiotic resistance make evaluation of any policy banning AGP challenging. In a recent review of published data, most resistance problems for humans are shown to arise from human use of antibiotics, but how resistant organisms colonize the gut or transfer resistance genes in humans is not known (Phillips et al., 2004).

Because of the lack of knowledge and the uncertainty surrounding the science of antimicrobial resistance, we think it is important to document carefully the productivity impacts of AGP. Prior analyses of the productivity impacts and the associated economic value of subtherapeutic use of antibiotics in U.S. swine production have been based on data from 1995 or earlier (Miller et al., 2003; Cromwell, 1991, 2002; Losinger et al., 1998a, b; Hays, 1977; Zimmerman, 1986; Butz, 1971).

A high proportion (over 60%) of U.S. pig grower/finisher producers report using AGP, suggesting producers value the AGP input. Improved productivity from AGP can occur by decreasing disease prevalence, increasing average daily gain (ADG), decreasing (improving) the feed conversion ratio (FCR), or decreasing the mortality rate (MR), among other measures. Miller et al. (2003) conclude that subtherapeutic use of antibiotics was associated with improved ADG (0.5%) and FCR (1.1%); these two productivity gains considered together improved net farm profits by 9%.

Hayes et al. (2001, 2002) and Hayes and Jensen (2003) modeled meat supply and demand changes from antibiotic use. Their model is based on productivity impacts of antibiotics from European data which include effects on both weaned pigs and grow/finish pigs. The authors conclude that a ban on over-the-counter antibiotics would increase production costs by \$6.05 per head initially, and by \$5.24 ten years post-ban. Subtherapeutic use of antibiotics results in lower costs of production for pork supplied to the markets and lower prices to consumers, ceteris paribus, providing benefits for consumers and producers alike. In another study using European data, Brorsen et al. (2002) document that age at weaning, mortality, feed conversion, and therapeutic use of antibiotics increased after implementing the AGP ban (all four measures changed in an undesirable direction). However, current AGP usage may not accurately reflect optimal AGP use given the improvements in animal production and genetics, especially those seen in the last 5–10 years.

Dritz et al. (2002) evaluated the effects of various regimens for antibiotics on ADG and FCR. They found that treated (those receiving antibiotics) nursery pigs had significantly higher ADG than did control pigs. However, no significant differences in ADG or FCR were found in finishing pigs. Likewise, Kjeldsen (2002) reported that removal of AGP had significant negative consequences for weaned pig production, with observed increased mortality and reduced gain. While Kjeldsen found the majority (63%) of finisher herds experienced no long-term change in ADG when AGP use was discontinued, 26% of the finisher herds did experience a temporary decrease in ADG when AGP applications ceased.[1]

The literature does seem to suggest that the productivity gains from AGP may be diminishing (there is a trend of somewhat lower productivity gains in more recent studies compared with earlier investigations). Further analysis using the most recent available data to address the issue and evaluate further potential policy regulations is warranted.

Toward this end, the objective of this study is to evaluate the productivity and economic impacts of antibiotic use for pig grower/finisher producers at the farm level using data from the USDA's National Animal Health Monitoring System (NAHMS) Swine 2000 Survey. Earlier research is extended in four dimensions. First, we measure pork productivity with four different indices, where previous models included only three. Second, our model considers possible structural relationships among the four productivity measurements; to our knowledge, simultaneous (or system) econometric estimates of the productivity impacts of AGP on these measures have not been previously reported in the literature. Third, our study uses NAHMS 2000 data—the most recent public data available—to investigate current productivity impacts of AGP. Finally, two scenarios related to AGP are evaluated for the impact expected on individual producer profits.

## Data

Data were derived from the NAHMS Swine 2000 Survey. A total of 2,499 farms (i.e., production units) in the top 17 swine-producing states in the United States were surveyed; NAHMS obtained additional data from only a subset of farms. Included were data on general management (from the complete set of 2,499 farms), antibiotic use, swine diseases and preventive practices (from a subset of 895 farms surveyed),

[1] It is noted that return to baseline levels of a productivity measure such as ADG is not the same as there being no long-term change.

and pig productivity, bio-security, and environmental practices (from a further subset of 799 farms surveyed). Farms with incomplete data (with regard to the variables of interest) were screened out of the data set. Thus, for this analysis, the final data set was comprised of data from 315 grower/finisher pig farms that participated in all three of the NAHMS swine surveys and provided complete data.

## Modeling Antibiotic Productivity Impacts

### *Productivity Measures*

Four endogenous productivity measures [average daily gain (*ADG*), feed conversion ratio (*FCR*), mortality rate (*MR*), and stunted rate (*SR*)] were employed. These variables are important to live weight (and carcass weight) of market pigs, percentage of standard or substandard market pigs, price received for pigs, or costs of production. *ADG* is defined as the gain per pig during the grow/finish period divided by the number of days in the period; *FCR* is the pounds of feed used per pound of live weight gain during pig finishing (Losinger, 1998); *MR* is calculated as the number of deaths divided by the average pig inventory [the natural log transformation of *MR* is used, with $LMR = \ln(MR/(1 - MR))$]; *SR* is calculated as the number of stunted pigs sold divided by the average pig inventory [the natural log transformation of *SR* is used, with $LSR = \ln(SR/(1 - SR))$]. Each variable measures a specific productivity dimension, and collectively they measure more accurately the overall productivity performance of a finishing herd.

### *Exogenous Variable Selection*

The NAHMS Swine 2000 Survey data provided over 1,200 possible exogenous variables corresponding to various queries in the survey. The selection and exclusion of variables as potential exogenous variables were based primarily on production practices in the swine industry, previous experimental or observational studies on swine productivity, and relevance to addressing questions related to AGP use. Relevant variables included general categories such as animal health and disease, management, facility, ration, operation size, bio-security, and region, plus antibiotic use variables. For AGP use, the sum of the days over which AGP applications were fed during the grower-finisher period was handled categorically as *AGP*$-$, with the bounding sum of days of AGP feeding for the category on either side of the dash. Some variables were combined to form indices and avoid information loss while simultaneously decreasing the model's degrees of freedom.

Definitions and descriptive statistics of variables used and retained are given in table 1. No specific relationships are hypothesized between these variables and productivity measures, in part because of the lack of a specific time dimension with these data. For example, disease preventive practices may well have a negative association with a productivity measure such as mortality because a farm may experience disease and increased mortality and then increase preventive practices

**Table 1. Variables Related to Growing/Finishing Pig Productivity: Variable Names, Definitions, and Descriptive Statistics**

| Variable | Definition | Mean or Proportion | Standard Deviation |
|---|---|---|---|
| **Endogenous Variables:** | | | |
| *ADG* | Average daily gain (lbs.) | 1.672 | 0.184 |
| *FCR* | Feed conversion ratio | 2.980 | 0.384 |
| *LMR* | ln(mortality rate/(1 ! mortality rate)) | !3.654 | 0.658 |
| *LSR* | ln(stunted rate/(1 ! stunted rate)) | !5.817 | 2.652 |
| **Antibiotic Use Variables:** | | | |
| *AGP0* | Antibiotics for growth promotion NOT used in feed (dummy variable) | 0.395 | 0.489 |
| *AGP1-30* [a] | Antibiotics for growth promotion used in feed 1–30 total days (dummy variable) | 0.086 | 0.280 |
| *AGP31-60* [a] | Antibiotics for growth promotion used in feed 31–60 total days (dummy variable) | 0.140 | 0.347 |
| *AGP61-90* [a] | Antibiotics for growth promotion used in feed 61–90 total days (dummy variable) | 0.098 | 0.298 |
| *AGP91-up* [a] | Antibiotics for growth promotion used in feed 91 or more total days (dummy variable) | 0.283 | 0.451 |
| *ADP1-30* | Antibiotics for disease prevention used in feed 1–30 total days (dummy variable) | 0.241 | 0.429 |
| *ADT$Num* | Number of antibiotics used for disease treatment | 0.869 | 1.007 |
| *ADT$Days* | Number of days antibiotics used for disease treatment | 15.330 | 26.343 |
| *AGP$Num* | Number of antibiotics used for growth promotion | 0.876 | 0.849 |
| **Animal Health/Disease Variables:** | | | |
| *DeathReason$Num* | Number of reasons given for death in grow/finish stage | 3.844 | 1.594 |
| *Prevent$Num* | Number of prevention practices in grow/finish stage | 2.531 | 1.068 |
| *Dis$Num* | Number of diseases observed in grow/finish stage | 3.286 | 2.290 |
| **Management Variables:** | | | |
| *D$Contract* | Contract producer (dummy variable) | 0.286 | 0.452 |
| *HoldingDays* | Days in the grow/finish stage | 114.800 | 19.724 |
| *OffsiteSource* | Proportion of pigs obtained from auctions, salebarns, or livestock markets | 0.040 | 0.193 |
| **Facility Description/Bio-security Variables:** | | | |
| *D$Confinement* | Total confinement (dummy variable) | 0.781 | 0.414 |
| *D$AI/AO* | All-in/all-out (dummy variable) | 0.533 | 0.500 |
| **Ration Variables:** | | | |
| *D$Ration3-4* | Use of 3–4 rations (dummy variable) | 0.435 | 0.497 |
| *D$Ration5-up* | Use of 5 or more rations (dummy variable) | 0.457 | 0.499 |

( continued . . . )

**Table 1. Continued**

| Variable | Definition | Mean or Proportion | Standard Deviation |
|---|---|---|---|
| **Geographic Region Variables:** [b] | | | |
| *D$EastCentral* | East Central region (Illinois, Indiana, Iowa, and Ohio) (dummy variable) | 0.387 | 0.488 |
| *D$Northern* | Northern region (Michigan, Minnesota, Pennsylvania, and Wisconsin) (dummy variable) | 0.206 | 0.405 |
| *D$WestCentral* | West Central region (Colorado, Kansas, Nebraska, Missouri, and South Dakota) (dummy variable) | 0.286 | 0.452 |

*Note:* There are 14 dummy variables among the 26 total variables.

[a] AGP use categories are for total days of AGP in the feed. These days could occur in one or more blocks of days at any time during the feeding period. For example, 30 days of AGP use could occur by feeding AGP for 30 days at any time in the grower/finisher stage, or in two 15-day blocks at any time, etc. Of course, *AGP91-up* implies close to continuous use of AGP during the grower/finisher stage.

[b] The Southern region (Arkansas, North Carolina, Oklahoma, and Texas) is the reference (baseline) group.

to deal with the disease. Without the time dimension, these relationships become obscure. But the main reason to include such variables in this analysis is to remove the effect they are likely to have in order to observe more accurately the associations between productivity and AGP.

### *System Specification*

The following estimations were performed: (*a*) a separate equation for each productivity measure (*ADG*, *FCR*, *LMR*, and *LSR*) using ordinary least squares (OLS) or maximum-likelihood methods; and (*b*) estimation by seemingly unrelated regression (SUR), combining equations for *ADG*, *FCR*, *LMR*, and *LSR* into a related production system.

The error structure and possible relationships between productivity variables were considered. Data were cross-sectional, with four different productivity measures per farm. Because there may have been factors common to a farm that affected simultaneously all productivity (outcome) measures, error dependence between equations could occur. Such error dependence might make independent estimation by OLS for each productivity measure inefficient, although the estimated parameters would be unbiased and consistent. Thus, dependence among the error terms between equations was accounted for by SUR.

We used OLS results to choose variables for inclusion in the SUR estimation. Variables presented to the SUR estimation were those from the OLS estimations where $P < 0.20$. Estimated coefficients were examined for stability by using subsamples derived from the observation set used. Ten subsamples were drawn—each consisting of a random sample of 95% of the observations used for the baseline model. The Hausman test was employed to conduct pairwise comparisons of the difference between the baseline model and the models using subsamples of the data

(Greene, 2003). Of the 40 pairwise comparisons performed, the Wald statistic was significant ($P < 0.05$) in one of the 10 comparisons for three of the productivity equations; we would expect to find two significant Wald statistics from such an analysis by chance alone. Thus, we interpret these results to indicate that the parameter estimates were stable.

A linear form production system was chosen because of its simplicity and because of the limitations of categorical data (14 of 26 of our variables are categorical) as independent variables. All equations use linear functional forms. The logit transformations for mortality rate (*LMR*) and stunted rate (*LSR*) were used to decrease inaccuracy of linear models for bounded variables (in this case from 0 to 1) and predictions outside the probability range (Zhao, Cheng, and Schaffner, 2001).

Accordingly, the form of the estimated SUR swine production system is given by:

$$(1)\qquad ADG = \beta_{1,1}x_{1,s} + \beta_{1,2}x_{2,s} + \ldots + \beta_{1,r}x_{r,s} + \varepsilon_{1,s};$$

$$(2)\qquad FCR = \beta_{2,1}x_{1,s} + \beta_{2,2}x_{2,s} + \ldots + \beta_{2,r}x_{r,s} + \varepsilon_{2,s};$$

$$(3)\qquad \ln(MR) = \beta_{3,1}x_{1,s} + \beta_{3,2}x_{2,s} + \ldots + \beta_{3,r}x_{r,s} + \varepsilon_{3,s};$$

$$(4)\qquad \ln(SR) = \beta_{4,1}x_{1,s} + \beta_{4,2}x_{2,s} + \ldots + \beta_{4,r}x_{r,s} + \varepsilon_{4,s}.$$

Independent variables ($x_{i,s}$) were those particularly important for explaining the four productivity measures (*ADG*, *FCR*, *LMR*, *LSR*) and included in particular variables which reflected AGP use.

### Estimation of Antibiotic Impacts on Pig Productivity

Variable descriptions, along with their associated means, and standard deviations (or proportions for the case of categorical variables) for variables retained in the SUR and OLS estimations are listed in table 1. Estimated coefficients, with associated statistics, are outlined for each estimated equation (tables 2–5). The SUR system's related $R^2$ was 0.12.

There were 10 independent variables used to explain average daily gain (ADG) (table 2). The effect of AGP was significant and was dependent on the amount of time AGP was fed. The ADG was highest when AGP was fed between 61 and 90 days (*AGP61-90*), with an associated increased ADG of 0.095 pounds (5.6% improvement) compared with no AGP. Other antibiotic use variables were generally not significant, except that use of ADP for less than 30 days was associated with a decrease in ADG. The number of different antibiotics administered, either for growth promotion or disease prevention, was not significantly related to ADG. In addition to antibiotic use variables, other explanatory factors also contributed to variation in ADG. These variables included *D$AI/AO*, the use of all-in/all-out pig flow (associated with an increased ADG of 0.028); number of different feed rations (*D$Ration5-up*, associated with an increased ADG of 0.038 if five or more different

**Table 2. Exogenous Variables Associated with Average Daily Gain (ADG) in Growing/Finishing Pigs**

| | SUR | | | OLS | | |
|---|---|---|---|---|---|---|
| Variable | Coefficient | Std. Error | *P*-Value | Coefficient | Std. Error | *P*-Value |
| Intercept | 1.656 | 0.031 | 0.000 | 1.651 | 0.032 | 0.000 |
| *AGP1-30* | 0.045 | 0.038 | 0.244 | 0.043 | 0.038 | 0.261 |
| *AGP31-60* | 0.056 | 0.031 | 0.069 | 0.053 | 0.031 | 0.093 |
| *AGP61-90* | 0.095 | 0.036 | 0.009 | 0.093 | 0.036 | 0.011 |
| *AGP91-up* | 0.074 | 0.024 | 0.003 | 0.071 | 0.025 | 0.005 |
| *ADP1-30* | !0.041 | 0.024 | 0.097 | !0.041 | 0.024 | 0.097 |
| *D$AI/AO* | 0.028 | 0.021 | 0.184 | 0.030 | 0.021 | 0.154 |
| *OffsiteSource* | !0.079 | 0.053 | 0.139 | !0.090 | 0.055 | 0.102 |
| *DeathReason$Num* | !0.014 | 0.006 | 0.026 | !0.012 | 0.006 | 0.051 |
| *D$Ration5-up* | 0.038 | 0.020 | 0.065 | 0.038 | 0.020 | 0.067 |
| *D$Northern* | 0.046 | 0.025 | 0.070 | 0.044 | 0.025 | 0.081 |

**Table 3. Exogenous Variables Associated with Feed Conversion Ratio (FCR) in Growing/Finishing Pigs**

| | SUR | | | OLS | | |
|---|---|---|---|---|---|---|
| Variable | Coefficient | Std. Error | *P*-Value | Coefficient | Std. Error | *P*-Value |
| Intercept | 3.189 | 0.091 | 0.000 | 3.189 | 0.092 | 0.000 |
| *D$Confinement* | !0.204 | 0.049 | 0.000 | !0.197 | 0.049 | 0.000 |
| *D$AI/AO* | !0.122 | 0.041 | 0.003 | !0.124 | 0.041 | 0.003 |
| *D$Ration 3-4* | !0.142 | 0.068 | 0.038 | !0.154 | 0.069 | 0.027 |
| *D$Ration5-up* | !0.174 | 0.069 | 0.013 | !0.185 | 0.070 | 0.009 |
| *D$Northern* | 0.234 | 0.074 | 0.002 | 0.240 | 0.075 | 0.001 |
| *D$WestCentral* | 0.180 | 0.070 | 0.011 | 0.188 | 0.071 | 0.008 |
| *D$EastCentral* | 0.141 | 0.067 | 0.038 | 0.145 | 0.068 | 0.034 |

rations are used); *OffsiteSource*, obtaining a higher percentage of pigs from offsite sources (associated with a decreased ADG of 0.079); *DeathReason$Num*, higher number of reasons for pig deaths (associated with a decreased ADG of 0.014); and a regional effect, *D$Northern* (pigs grown in the Northern region associated with improved ADG of 0.046).

Seven independent variables were significant in explaining variation in the feed conversion ratio (FCR) (table 3). No antibiotic use variables were statistically significant in explaining FCR. Factors associated with FCR were total confinement production (*D$Confinement* improved FCR, with an estimated coefficient of !0.204); all-in/all-out pig flow (*D$AI/AO* improved FCR, with an estimated coefficient of

! 0.122); number of rations (improved FCR, with estimated coefficients of ! 0.142 for 3–4 different rations and ! 0.174 for five or more different rations); and being from the Southern region of the United States (all estimated regional coefficients were positive relative to the baseline Southern region).

The number of days of AGP usage was not significant in explaining variation in pig mortality rate (LMR) (table 4). However, the number of days antibiotics were used for disease treatment (*ADT$Days*) was associated with improved (decreased) mortality. The number of different antibiotics used for disease treatment (*ADT$Num*) was associated with increased mortality rate. Additionally, the number of general preventive practices used (*Prevent$Num*) was associated with increased mortality. Farms with increased holding days (days to reach market weight) also were associated with higher mortality. The geographic regions outside the Southern region (baseline) were all associated with decreased LMR.

Decreases in the stunted rate (LSR) were generally associated with AGP (table 5). While some of the estimated coefficients were not statistically significant, when AGP usage ranged from 61 to 90 days, this was associated with a statistically significant decrease in LSR. Other independent variables associated with increased (poorer) LSR were confinement, being from a West Central state (Colorado, Kansas, Nebraska, Missouri, or South Dakota), and all-in/all-out pig flow. Number of rations being 3–4, and pigs in the West Central region were associated with decreased (improved) LSR.

The number of different AGP was found not to contribute to explaining productivity generally. *AGP$Num* did not appear as an explanatory variable in the ADG, FCR, or MR models, and was only marginally important (*P*-value = 0.197) in the SR model. In the SR model, the sign associated with *AGP$Num* is positive, suggesting that higher stunting rates are associated with the additional use of different antibiotics. This finding may be explained by the lack of time dependence in the model, i.e., the association might arise if production systems that assume relatively higher production losses due to stunting also incorporate greater numbers of antibiotics. While further research on this issue is needed, this finding suggests it might be possible to reduce or eliminate certain classes of antibiotics while still maintaining the productivity gains received from antibiotic use.

Because complete data were not obtained from all 2,499 farms initially surveyed, and because of missing data, a subset comprised of 315 farms was used in this analysis. Differences in herd size were examined in order to determine if the farms used for analysis were representative of a random sample of farms (one of the strengths of the NAHMS survey). The data set used for analysis had a mean total herd size of 11,005 pigs compared to the full NAHMS data set which had a mean herd size of 5,549 (*P* = 0.08). Consequently, our results may be more representative of larger swine farms. Swine farms that produce at least 5,000 head or more per year produce most (53%) of the hogs in the United States (USDA/National Agricultural Statistics Service, 2002).

The results reported from OLS regression were similar to those from the SUR, but there were some differences. The estimated parameters and their corresponding

**Table 4. Exogenous Variables Associated with Mortality Rate (MR) in Growing/Finishing Pigs**

| | SUR | | | OLS | | |
|---|---|---|---|---|---|---|
| Variable | LMR [a] (Std. Error) | MR [b] | *P*-Value | LMR [a] (Std. Error) | MR [b] | *P*-Value |
| Intercept | !4.265 (0.255) | 0.014 | 0.000 | !4.322 (0.258) | 0.014 | 0.000 |
| *ADT$Num* | 0.156 (0.053) | 0.005 | 0.003 | 0.179 (0.053) | 0.006 | 0.001 |
| *Dis$Num* | 0.054 (0.015) | 0.002 | 0.000 | 0.054 (0.015) | 0.002 | 0.001 |
| *ADT$Days* | !0.003 (0.001) | 0.000 | 0.011 | !0.004 (0.001) | 0.000 | 0.010 |
| *Prevent$Num* | 0.084 (0.032) | 0.002 | 0.010 | 0.092 (0.033) | 0.003 | 0.009 |
| *HoldingDays* | 0.003 (0.001) | 0.000 | 0.053 | 0.004 (0.001) | 0.000 | 0.048 |
| *D$Northern* | !0.190 (0.126) | !0.006 | 0.130 | !0.194 (0.127) | !0.006 | 0.097 |
| *D$WestCentral* | !0.232 (0.125) | !0.007 | 0.062 | !0.217 (0.126) | !0.006 | 0.060 |
| *D$EastCentral* | !0.202 (0.116) | !0.006 | 0.080 | !0.193 (0.117) | !0.006 | 0.065 |

[a] Coefficient for LMR is where LMR = ln(mortality rate/(1 ! mortality rate)).
[b] Transformed coefficient for MR.

*P*-values were similar and stable (tables 2–5). The magnitude of the estimated coefficients was similar. However, some subtle differences can be observed among results from OLS and SUR. The impact of AGP on ADG estimated by OLS was somewhat less (estimated coefficients were smaller) than under the SUR regression. In addition, most estimated coefficients using OLS were higher than the estimated results using SUR in modeling FCR. The aggregation of those differences was examined using the Hausman specification test. This test suggested that there was a difference between the OLS and SUR estimations (test statistic = 52.8, $P = 0.06$). Given these results, the presentation above is focused on the results from the SUR analysis.

## Economic Impact from Banning or Adjusting AGP Use

A partial budget (Calkins and DiPietre, 1983) was used to estimate the economic impact for a producer for a 1,020-head pig barn. For simplicity, the economic impacts of ADG, FCR, LMR, and LSR were assumed not to be linked with one another in the budget beyond the association implied by the estimated SUR coefficients. The two scenarios modeled were a total ban on AGP, and an application of AGP close to what might be an economically optimal AGP use. Average pig

**Table 5. Exogenous Variables Associated with Stunted Rate (SR) in Growing/ Finishing Pigs**

| | SUR | | | OLS | | |
|---|---|---|---|---|---|---|
| Variable | LSR [a] (Std. Error) | SR [b] | *P*-Value | LSR [a] (Std. Error) | SR [b] | *P*-Value |
| Intercept | !5.167 (0.256) | 0.006 | 0.000 | !5.147 (0.257) | 0.006 | 0.000 |
| *AGP$Num* | 0.236 (0.183) | 0.005 | 0.197 | 0.247 (0.185) | 0.005 | 0.182 |
| *AGP1-30* | 0.122 (0.400) | 0.002 | 0.759 | 0.139 (0.402) | 0.003 | 0.729 |
| *AGP31-60* | !0.458 (0.374) | !0.007 | 0.221 | !0.454 (0.376) | !0.007 | 0.228 |
| *AGP61-90* | !0.841 (0.408) | !0.011 | 0.040 | !0.845 (0.411) | !0.011 | 0.040 |
| *AGP91-up* | !0.226 (0.356) | !0.004 | 0.527 | !0.211 (0.359) | !0.004 | 0.555 |
| *D$Ration3-4* | !0.271 (0.179) | !0.005 | 0.132 | !0.269 (0.180) | !0.005 | 0.136 |
| *D$Confinement* | 0.408 (0.213) | 0.010 | 0.057 | 0.376 (0.215) | 0.009 | 0.082 |
| *D$AI/AO* | 0.276 (0.180) | 0.006 | 0.126 | 0.265 (0.181) | 0.006 | 0.143 |
| *D$WestCentral* | !0.603 (0.203) | !0.009 | 0.003 | !0.616 (0.204) | !0.009 | 0.002 |

[a] Coefficient for LSR is where LSR = ln(stunted rate/(1 ! stunted rate)).

[b] Transformed coefficient for SR.

prices and costs of production data from 1999–2001 (Miller, Song, and Bahnson, 2001; University of Illinois, 2002; USDA/National Agricultural Statistics Service, 2000–2002) were used. The live weight price for standard market hogs was assumed to be $40.17 per cwt; the price for nonstandard market hogs (i.e., the price applied to pigs marketed that were considered stunted pigs) was $20.08 (the ratio of the prices of standard to stunted pig prices used in Miller, Song, and Bahnson averaged 2:1). A price penalty matrix, reported by Miller, Song, and Bahnson (2001), was used for varying weight deviation of market hogs from the standard weight. The average entry weight assumed for market hogs was 59 pounds (PigCHAMP®, 1999).[2] Finally, the average time hogs remained in the finishing stage was 115 days (NAHMS 2000 Survey data).

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[2] NAHMS gives 60+ pounds as a guideline for determining if data apply to the grower/finisher stage of production, but a specific weight at movement to grow/finish is not provided in NAHMS data—thus the need for using the PigCHAMP® data.

Individual pig weights of 1,020 pigs were simulated and based on assumed normal distributions of live market weight, with mean pig weights derived from each scenario and an assumed standard deviation of live market weights of 16.69 pounds (PigCHAMP®, 1999; Hamilton et al., 2003). Using the @RISK computer program, we created a normal distribution of 5,000 pig weights based on the assumed starting weights, the ADG for the scenario, and the assumed standard deviation of live market weights. We drew from this distribution 1,020 head (a standard barn size), and applied an assumed pricing matrix for the standard market weight pigs. Stunted pigs were assumed to be sold at 50% of the base price (Miller et al., 2003). Since feed conversion did not change (table 6), we accounted for feed savings with changes in the weights of marketed pigs. The assumed pig flow was not changed based on the antibiotic scenarios. Estimates were made for increased revenues, decreased costs, decreased revenues, and increased costs to capture the net impacts for producers. Net impacts were estimated for changes in each productivity measure implied by AGP use while also holding the other productivity measures constant at their averages in the NAHMS 2000 Survey data. An average mortality rate (MR) of 0.021 was assumed (table 6).

The influence of a ban on producer profitability was estimated by projecting changes in each of the four productivity measurements from the baseline model. The baseline model reflects the current AGP use profiles of swine finishers in the NAHMS Swine 2000 Survey. Of swine finishers, 39% did not use AGP, 8.6% reported using AGP for 1–30 days, 14% for 31–60 days, 9.8% for 61–90 days, and 28.3% for more than 90 days.

### *Scenario 1. A Ban on AGP*

As observed from table 6, a ban on AGP will decrease ADG from 1.684 to 1.642 and will increase SR from 0.019 to 0.023. The producer will realize an estimated loss of $1,400 in profits from a ban on AGP for each 1,020-head barn of pigs compared with the current AGP use profile of U.S. producers. These productivity and economic impacts are substantially higher than results reported in previous work (Miller et al., 2003) where the estimated profits increased by only $0.59/pig marketed from AGP use. However, estimates found here are still less than half those reported by Hayes et al. (2002). The Hayes et al. model includes all over-the-counter antibiotic use, while we consider only AGP. Moreover, because Hayes et al. model the effects of both the weaned pig stage and the grow/finish stage, their results are not exactly comparable to this study. Still, these results suggest the use of AGP continues to be an important contributor to improved productivity in swine production.

### *Scenario 2. Limiting Use of AGP to 2–3 Months*

Clearly, given that antibiotics do enhance productivity, an important question needing to be addressed is the potential impact on grower/finisher pig producers if AGP application were close to what may be the optimal use for the industry. Thus,

**Table 6. Productivity for Growing/Finishing Pigs Under Two Scenarios: A Ban of AGP, and a More Optimal Use of AGP**

| | SCENARIOS | | |
|---|---|---|---|
| Productivity Measure [a] | Baseline [b] | Ban AGP | More Optimal AGP Use (61–90 days) |
| ADG (lbs.) | 1.684 | 1.642 | 1.736 |
| FCR | 2.992 | 2.992 | 2.992 |
| MR | 0.021 | 0.021 | 0.021 |
| SR | 0.019 | 0.023 | 0.010 |
| Mean market hog weight (lbs.) | 252.64 | 247.89 | 259.84 |
| Net impact per 1,020-head barn | N/A | ! $1,400 | $1,992 |

[a] ADG = average daily gain, FCR = feed conversion ratio, MR = mortality rate, and SR = stunted rate.
[b] Baseline reflects current antibiotic use profile (see table 1).

this scenario provides an economic polar extreme to the antibiotic ban scenario. This is also a relevant scenario for consideration because 28.3% of producers currently feed AGP for more than 90 days (table 1), and these producers might be more accepting of restricting use to a lower number of days than to a ban on all use should this be a policy-relevant choice given the current debate on antibiotic use.

This scenario assumes AGP will be fed for 61–90 days for all farms. Under this scenario, ADG increases from 1.684 to 1.736 pounds; SR also improves from 0.019 to 0.01 (table 6). The producer will realize an estimated gain of $1,992 in profits for each 1,020-head barn of pigs compared with the current AGP use profile of U.S. producers.

Under the limited (no more than 90 days) use of AGP, selection pressure for antimicrobial resistance would be reduced on farms where current AGP usage exceeds 90 days, but selection pressure would increase on farms where AGP applications are currently used less than 61 days. Some policies such as these merit further consideration. This change in usage pattern would allow the productivity gains from AGP use while partially limiting the antibiotic resistance development.

There are reasons why not all producers are applying AGP use in the 61–90 day range. Our model assumes one pricing structure that applies to all farms. But there may be farmers who can achieve higher profits with no antibiotic use because of niche marketing (e.g., through organic channels, or to specific international markets which require no antibiotic use). Also, not all producers may be aware of the productivity gains possible with antibiotic usage, even if they are not targeting specific markets that restrict AGP feeding. Additionally, the data and information available from the NAHMS 2000 Survey necessarily limit our ability to model production practices or unobserved on-farm environmental details that may affect productivity. Producers, with their unique information about their own herds and production practices, may be able to combine inputs in more productive ways than our model can represent. If these specialized but unobserved practices are associated with antibiotic use, our estimated results may overstate or understate the productivity impact of AGP use.

## Summary and Policy Implications

Using NAHMS Swine 2000 Survey data, this study continues to show substantial productivity gains from antibiotic use in the grower/finish stage of pig production. Results confirm the value of antibiotics for growth promotion (AGP) in feed from an economic perspective, and suggest higher productivity and profitability can be realized with AGP application in the grower/finisher stage of production than found with the earlier 1990–95 NAHMS data. Findings suggest that a complete ban of AGP would cost grower/finisher pork producers approximately $1,400 per 1,020 pigs placed. In contrast, using AGP for 61–90 days would enhance producer profits by $1,992 per 1,020 pigs placed compared with the current profile of AGP use.

This study updates and extends the previous work of Miller et al. (2003) who used NAHMS 1990–95 data in their analysis of productivity and economic impacts of feedgrade antibiotic use in pork production. First, maximum production from antibiotics appeared to occur when AGP applications were fed between 61 and 90 days. However, 28.3% of swine farmers reported using AGP for more than 90 days. Decreasing the amount of time of AGP usage to less than 90 days may be cost-beneficial. Second, the number of different antibiotics used for growth promotion was found not to contribute to productivity. While further research on this issue is needed, this finding suggests it may be possible to reduce or eliminate certain classes of antibiotics while still maintaining the productivity gains received from antibiotic use. Third, use of antibiotics for disease prevention (ADP) was not important in improving productivity. Finally, a total ban on subtherapeutic use of antibiotics would be associated with substantially decreased profits for individual swine producers.

Producers using AGP in the grower/finisher stage for periods between 61 and 90 days may be operating closer to the economic optimum. Using AGP for shorter time periods will decrease antibiotic resistance pressures.

It may be possible for producers to employ management techniques to improve productivity if the use of AGP is banned in the United States. For example, receiving pigs from an on-site source (effectively operating a closed herd) was associated with improved average daily gain (ADG). Improved diets tailored more closely to the pigs' needs (captured as number of different diets in our analysis) were associated with improved feed conversion ratio (FCR). Such management-focused strategies are also being pursued in Danish pork production following the ban of AGP in Denmark (Kjeldsen, 2002).

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